J Immigrant Minority Health
DOI 10.1007/s10903-013-9856-y

ORIGINAL PAPER

Indoor Air Quality Survey of Nail Salons in Boston

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Abstract Employees in nail salons, largely Vietnamese immigrant women in Boston, are exposed to a range of volatile organic chemicals from the products used in salons, including solvents, glues and polishes. Some of these chemicals have the potential to cause short and long-term adverse health effects. Only limited research has been performed on assessing occupational exposures. This project aimed to characterize total volatile organic compound (TVOC) and $PM_{2.5}$ concentrations in nail salons as a function of ventilation, building characteristics, customer and employee occupancy, and type of services being performed. Students conducted sampling in 21 salons in Boston, MA from September to December, 2011. Study visits included: indoor environmental quality measurements (TVOCs, $PM_{2.5}$ and carbon dioxide), site observations, and an interview. CO_2 levels in 15 of 21 salons exceeded 800 ppm, suggesting that these salons may have insufficient ventilation. Higher TVOC and $PM_{2.5}$ levels were found in salons with less ventilation (as estimated using CO_2 concentrations). Contrary to our a priori hypothesis, average levels of TVOCs, CO_2 and $PM_{2.5}$ were consistent throughout salons, indicating that exposures may not be restricted to areas in the salon where work is being performed (e.g., at the manicure table). Higher TVOC concentrations were observed when tasks were being performed, yet were not dependent upon the number of tasks being performed. Improving ventilation conditions in salons to meet minimum outdoor air delivery requirements can reduce exposures to TVOCs.

Keywords Nail salon · Vietnamese · Ventilation · TVOC · Particulate matter

Introduction

The number and popularity of nail salons has grown dramatically in the United States in recent years. In 2006, it was estimated that there were over 58,000 beauty salons in the US with over 350,000 licensed nail technicians [1]. An overwhelming majority of nail salon workers are of Asian descent; Vietnamese immigrants, in particular, have been estimated to represent 59 % of the workforce in this field [2]. Personal care products handled regularly by nail salon employees contain a wide array of chemicals that are known or suspected to be associated with skin and eye irritation, allergies, neurologic or reproductive effects [3–5]. Products used include solvents, glues, polishes, hardeners, and other agents, and may contain formaldehyde, toluene, dibutyl phthalate (DBP), methyl ethyl ketone, ethyl acetate, acetate, methyl methacrylate, methacrylic acid (MMA) and/or acetonitrile [5–7].

Due to the exposure concerns from using these products, several studies have been conducted to evaluate occupational exposures. An early study measured personal and area samples for organic vapors and polymethacrylate dust in 20 female nail sculptors and 20 matched controls [3]. They found that the salon workers were exposed to

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Published online: 14 June 2013

multiple chemicals at levels lower than US Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits and other standards, yet they did identify throat irritation as a statistically significant health effect among nail sculptors. More recently, Quach et al. [8] performed a study to characterize workplace exposures in California nail salons. They measured personal and area concentrations of toluene, ethyl acetate and isopropyl acetate among 80 workers in 20 salons using personal air monitors. They found that measured levels of the chemicals considered in this study were higher than the recommended guidelines to prevent health symptoms such as headaches and breathing problems. In 2012, Roelofs et al. [5] published results of a survey of nail salons conducted in 2006 that included measurements of carbon dioxide inside salons and a description of the type of ventilation. The study found that only 8 of 22 salons had mechanical ventilation systems, and 73 % of salons were not meeting minimum ventilation requirements. The impact of the low ventilation on worker exposure could not be directly explored because the study did not include measurements of airborne chemicals.

Working in a salon has been associated with a number of health effects. A survey of salon workers in North Carolina found associations between spontaneous abortions and the numbers of hours worked per day, the number of chemical services performed with the use of formaldehyde-based disinfectants and the work in salons where other employees performed nail sculpturing [9]. In a health-effects survey conducted in Boston, self reported health effects such as skin problems, respiratory irritation, musculoskeletal disorders and headaches were reported as work-related in conjunction with poor air and offensive odors [10]. Objective measures of health effects, such as lung function and lung inflammation, were used by researchers from the National Institute of Occupational Safety and Health (NIOSH) in a health evaluation study of nail salon technicians from Midwestern US states. Researchers found that small but significant decrements in lung function and increased airway inflammation were associated with the number of years employed as a nail technician and the number of hours exposed to acrylic gel. Also, nail technicians reported more wheezing apart from colds and eye irritation than the controls, but the differences were non-significant [11].

To more fully understand exposures that occur in this workforce, the Environmental Health and Justice JBS ("Justice Brandeis Semester") at Brandeis University investigated chemical exposures, and the factors that influence those exposures, in nail salons located in Boston, Massachusetts. Following a community-based participatory-research study design, the research team from Brandeis collaborated with a local Vietnamese community and economic development organization [the Vietnamese-American Initiative for Development, Inc. (Viet-AID)] and the Boston Public Health Commission.

Methods

Overview

In the Fall of 2011, we recruited 21 nail salons in lower-income neighborhoods in Boston (Dorchester, Roxbury, Jamaica Plain and Mattapan neighborhoods) and conducted short-term measurements of several air quality parameters during working hours. We identified the majority of salons through information provided by the Boston Public Health Commission (BPHC); BPHC provides training and/or permits through the Safe Nail Salon project, an educational program implemented to improve nail salon safety. A total of sixty salons were solicited from the BPHC training roster to take part in the study. Other salons were identified through canvassing of neighborhoods during the recruitment process using a flyer printed in both English and Vietnamese. The study design was reviewed by the Institutional Review Board (IRB) at Brandeis University. The results of this study were translated into Vietnamese by our Viet-AID partners and also presented at a Safe Nail Shops project hosted by the BPHC.

Air Monitoring Protocol

Each site visit consisted of three parts: indoor environmental quality measurements, site observations, and a short interview with the salon owner. Multiple indoor environmental quality parameters were measured at each location and included carbon dioxide (CO_2), used as a proxy for ventilation in the salons, temperature, relative humidity (Q-Trak Model 8551; TSI, Inc.), particulate matter with a mass median aerodynamic diameter of 2.5 microns or less ($PM_{2.5}$; Dustrak Model 8520; TSI, Inc.), and total volatile organic compounds (TVOCs;ppbRAE; RAE Systems, Inc.). Samples were collected in 30 s intervals at each predetermined sample location within each salon. The process was then repeated so that two measurements were obtained at each location at different time points. An average of seven sampling locations were selected in each salon, with the goal of obtaining measurements throughout the entire salon (i.e., both near and far from services and ventilation). The field sampling team created a floorplan of each salon that included general dimensions, ventilation characteristics (such as locations of doors and windows, table fans, ceiling fans and vents), and sampling locations.

Quality Assurance/Quality Control

All of the monitoring equipment used was calibrated prior to use in our study. For quality assurance, the two sets of equipment used during the study were placed side-by-side and duplicate samples taken to estimate instrument precision, and replicate samples were recorded in four nail salons. This analysis showed good agreement between sampling devices and replicate samples. Outdoor samples were obtained to estimate the influence of $PM_{2.5}$ and TVOC sources outside of each nail salon.

Questionnaire and Observations

To aid in the interpretation of the sampling results and understand factors that might influence worker exposure, we created a questionnaire and observation form to record the following information: hours of operation; peak hours and days; average length of shift; type of services offered; number and type of services that were being performed during the monitoring (e.g., pedicure, manicure, silk nails, gel nails, acrylic nails, waxing and airbrushing); type(s) of ventilation present (e.g., general/central ventilation system, open door/window, ceiling fan, local exhaust ventilation, fan in door/window, table vents, air "cleaners" or "purifiers", window air conditioner and table fans); size of the space (i.e., square footage and volume); location of nail salon with respect to roads (e.g., near highway, busy street or gas station); type of building (i.e., detached, basement or storefront); most common nail product brands used in the salon; number of workers and customers present; number of manicure, pedicure and hair stations; and use of personal protective equipment.

Data Analysis

Summary statistics were calculated for each parameter and data were visualized by creating bar graphs and scatter plots. Associations between environment parameters and salon characteristics were evaluated using scatter plots, Spearman correlation, Wilcoxon rank sum tests and generalized linear models (with natural log-transformed dependent variables to satisfy normality assumptions). All data analysis was performed using MS Excel, Sigmaplot and SAS statistical software.

Results

Salon Demographics

Of the sixty salons solicited to take part in the study, 21 salons agreed to participate (35 %). All of the participating salons offered manicure and pedicure services and none of them offered hair services. The size of the nail salons varied widely in our study population, as evidenced by the range in both size (89–613 m^3) and number of manicure and pedicure stations (3–18; 2–12, respectively), suggesting that our survey included a non-homogeneous group of nail salons. The number of sampling locations in each salon ranged from 4 to 9 (average = 7), depending on the salon size. The number and type of ventilation systems in each nail salon also varied: general/central ventilation system (18), table fans (16), open door/window (6), window air conditioner (6), ceiling fan (3), air "cleaners" or "purifiers" (3), local exhaust ventilation (1).

Air Monitoring Data

Summary statistics for the monitoring parameters are presented in Table 1. Salon average TVOC concentrations varied across the nail salons and were log-normally distributed; the median TVOC concentration was 4,800 ppb (range 61–38,000 ppb). Salon average $PM_{2.5}$ concentrations also varied across the nail salons and were log-normally distributed (median 18 μg/m^3; range 6.1–56 μg/m^3) While inter-salon variability for TVOCs and $PM_{2.5}$ was significant, intra-salon variability was low. The TVOC and $PM_{2.5}$ concentrations within the nail salons did not vary widely (median geometric coefficient of variation: 22 and 7 %, respectively); measurements collected in locations near where services were being performed were similar to those taken elsewhere in the salon. Short-term CO_2 concentrations ranged from 660 to 1,600 ppm. The recommended ventilation rate for a nail salon is 25 cfm/person which translates to an approximate steady state CO_2 concentration of 800 ppm assuming an outdoor CO_2 concentration of 375 ppm and typical indoor activity levels [12]. CO_2 levels in 15 of 21 salons exceeded 800 ppm.

Within-Salon Variability

The TVOC concentrations within the nail salons were generally consistent within each salon regardless of where the measurements were taken (e.g., near or far from where services were being performed). The distribution of individual TVOC measurements made in each salon, represented with boxplots, is presented in Fig. 1. Overall, there was low variability in TVOC concentrations within each salon. The figure does show a wider range for salons on the low end of the distribution of TVOC concentrations. These salons, represented by the first four boxplots, are those where services were not being performed at the time of sampling and the TVOC concentrations, while varied, are low and consistent with background TVOC concentrations in buildings. For the remaining salons, within-salon variability is much lower. These interpretations are further supported by analysis of the coefficient of variation. For salons without services being performed, the median CV is 0.50; for salons with service being performed, the median

Table 1 Distribution of salon average concentrations for the indoor monitoring parameters (TVOC, $PM_{2.5}$, CO_2)

Parameter	N	Minimum	25th Pctile	50th Pctile	75th Pctile	Maximum
TVOCs (ppb)	21	61	1,100	4,800	13,000	38,000
$PM_{2.5}$ (μg/m^3)	21	6.1	15	18	21	56
CO_2 (ppm)	21	660	800	1,100	1,300	1,600

CV is <0.20. Of note, one salon that had services being performed did have a wider degree of spread in the data points. This was not due to measurements taken near or far from where services were being performed; in this salon, services were initially not being performed when sample collection began, but a pedicure was started approximately halfway through the site visit. The initial TVOC concentrations were low and similar to salons where services were not being performed, and then increased as a pedicure was performed. Our spatial analysis has an important limitation. First, the field staff could not take measurements very close to where services were being performed because our agreement with salon owners was that we would not interfere with their work or potentially cause concern with customers. Our samples taken near where services were being performed are short-term area samples taken within a few feet of workers and customers, but they do not reflect the immediate breathing zone of the worker; TVOC concentrations may be greater within the immediate work area.

Predictors of Exposure Concentrations

To examine factors that may influence concentrations of TVOCs and $PM_{2.5}$ in the salons, we compared CO_2 concentrations to TVOC and $PM_{2.5}$ concentrations. Elevated CO_2 concentrations, and thus lower ventilation rates, were significantly and positively correlated with TVOC concentrations (Spearman $R = 0.73$; $p < 0.01$) (Fig. 2a). Higher CO_2 concentrations were also associated with

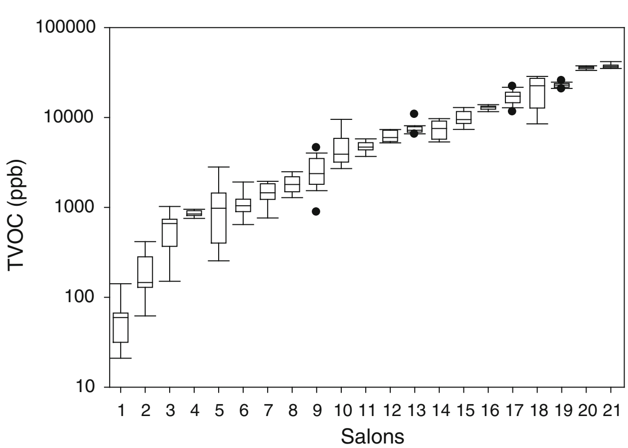

Fig. 1 Distribution of TVOC concentrations within each of the 21 salons in the study

higher $PM_{2.5}$ concentrations, generally, although this relationship was not as robust (Spearman $R = 0.27$; $p = 0.24$) (Fig. 2b); the correlation is stronger when one influential point is removed (Spearman $R = 0.41$; $p = 0.07$). The weaker correlation of $PM_{2.5}$ and CO_2 concentration relative to TVOC and CO_2 concentrations was not unexpected due to known outdoor sources of $PM_{2.5}$ that can infiltrate indoors (e.g., vehicle exhaust). Because of this, $PM_{2.5}$ measurements found inside salons are a mix of both indoor-generated and outdoor-generated particulate matter, while the TVOC measurements are specific to salon activities (outdoor TVOC concentrations are low, in general).

We also examined the data in relation to the number and type of services being performed during the site visit, and the type of ventilation systems observed. Nail salons where workers were performing services (pedicure, manicure, silk nails, gel nails, or acrylic nails) had significantly higher salon-average TVOC and $PM_{2.5}$ concentrations compared to salons where services were not being performed (TVOC: 11,000 vs. 600 ppb; 24 vs. 10 μg/m^3; Wilcoxon rank sum test, $p < 0.05$), confirming that exposures in salons are directly related to the services being performed (Fig. 3). Importantly, the number of services being performed was not a significant predictor of TVOC or $PM_{2.5}$ concentrations (generalized linear model, $p = 0.14$ and $p = 0.8$, respectively) the main determinant of TVOC concentration was whether at least one service was being performed, but was not impacted by the total number of services performed.

The analysis of type of service being performed and ventilation systems observed in relation to TVOC concentration was limited by small sample size and/or lack of variability and were generally null. However, in a multivariate regression analysis limited to salons where services were actively being performed ($n = 17$), there was suggestive evidence that acrylic nail services were positively associated with TVOC concentration; Salons with acrylic nail services being performed at the time of sampling had higher TVOC concentrations, on average, compared to those where acrylic nail services were not being performed, controlling for CO_2 concentration (generalized linear model, natural log-transformed dependent variable, $R^2 = 0.47$, $p > 0.05$). For ventilation, the distribution of TVOC concentrations was lower in salons that had doors or windows open during sampling (mean 5,000 vs. 11,000 ppb; analysis restricted to salons

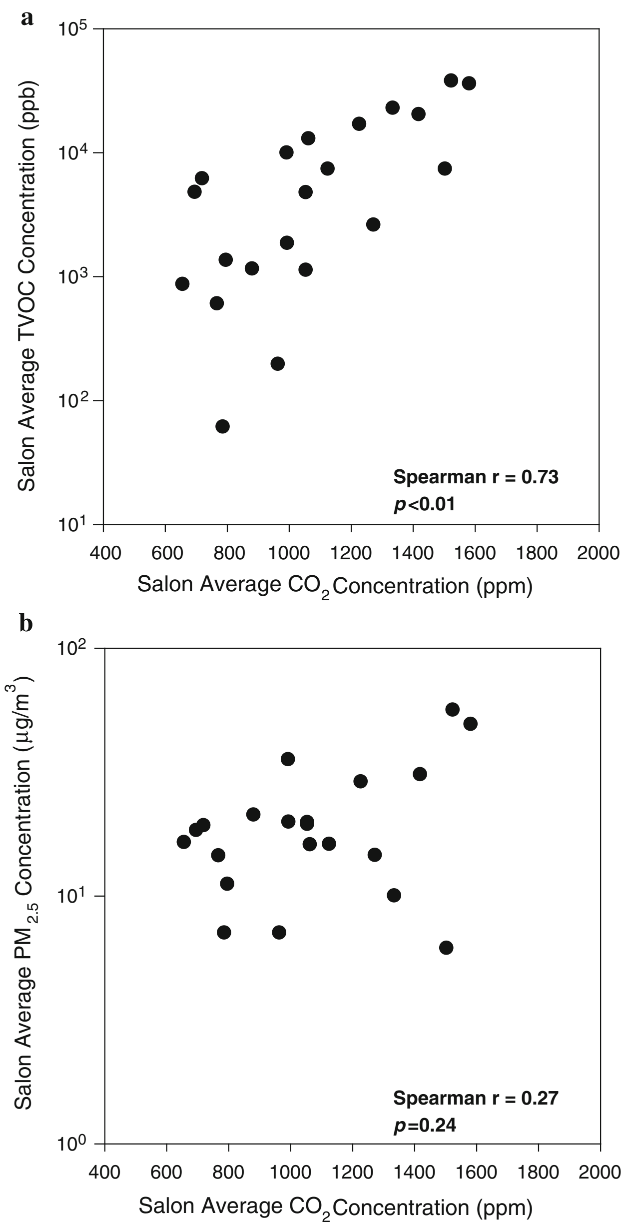

Fig. 2 a, b Relationship between salon average CO_2 concentration and salon average TVOC (1a) and $PM_{2.5}$ (1b) concentration

where services were actively being performed); no other observations regarding ventilation type appeared to be related to TVOC or $PM_{2.5}$ concentrations.

Discussion

In this study of 21 nail salons in Boston, Massachusetts, we partnered with Viet-AID and the Boston Public Health Commission to better understand chemical and particulate exposure of workers in nail salons and the factors that influence their exposure. $PM_{2.5}$ and TVOC concentrations were inversely associated with ventilation; salons with poorer ventilation, as indicated by higher CO_2 levels, had significantly higher TVOC concentrations. Contrary to our a priori hypothesis, average levels of TVOCs, CO_2 and $PM_{2.5}$ were fairly consistent throughout the nail salons, indicating that elevated exposures to workers may not be restricted to areas in the salon where work is being performed (e.g., at the manicure table). Higher TVOC concentrations were observed when tasks were being performed and were not dependent upon the number of tasks being performed.

The median salon averaged TVOC concentration in our study was 4,800 ppb, with a maximum level of 38,000 ppb. For comparison, a recent study of TVOC concentrations in homes reported an average concentration of 337 ppb [13]. Only three of the salons in our study had concentrations less than this value. To compare our results to other studies of TVOCs in occupational settings that report a mass-based concentration, we calculated our median and maximum concentrations as 11 and 87 mg/m^3, respectively (based on TVOC measurements being normalized to isobutylene). Our TVOC results are generally an order of magnitude higher than levels reported in similar work locations. For example, in a study of Finnish nail salons, TVOC concentrations ranged from 0.76 to 1.6 mg/m^3 [14]. In a study or Portuguese hair salons, the average TVOC concentration was 1.4 mg/m^3 [15]. In a study of beauty salons in Greece, TVOC concentration ranged from 0.1 to 14.5 mg/m^3 [16]. Caution is advised when comparing TVOC results from different studies due to limitations associated with the use of PIDs. This includes potential differences in the compound used for normalizing TVOC measurements (e.g., isobutylene vs. toluene) and the potential different mix of volatile compounds being measured which may require an upward or downward adjustment.

There are no standards for indoor $PM_{2.5}$ levels, but the EPA standard for outdoor $PM_{2.5}$ is 35 µg/m^3 averaged over a 24-h period [17]. While these standards were set for ambient (i.e., outdoor) particles, they provide a useful benchmark for gauging workers indoor exposures to particulate matter. Only two of the salons that we studied had short-term indoor $PM_{2.5}$ concentrations above 35 µg/m^3. Concentrations measured in homes provides another relevant benchmark for evaluating our results. In a study conducted in homes of 25 people in the Boston area, the average indoor $PM_{2.5}$ concentration was 10 and 12 µg/m^3 during winter and summer sampling campaigns [18]. More than 75 % of the salons in our study had higher indoor $PM_{2.5}$ concentrations than these homes from the same city, indicating that the salon levels are generally higher than residential environments, possibly due to generation of $PM_{2.5}$ in the salons from activities such as nail filing and/or poor ventilation with the outdoors.

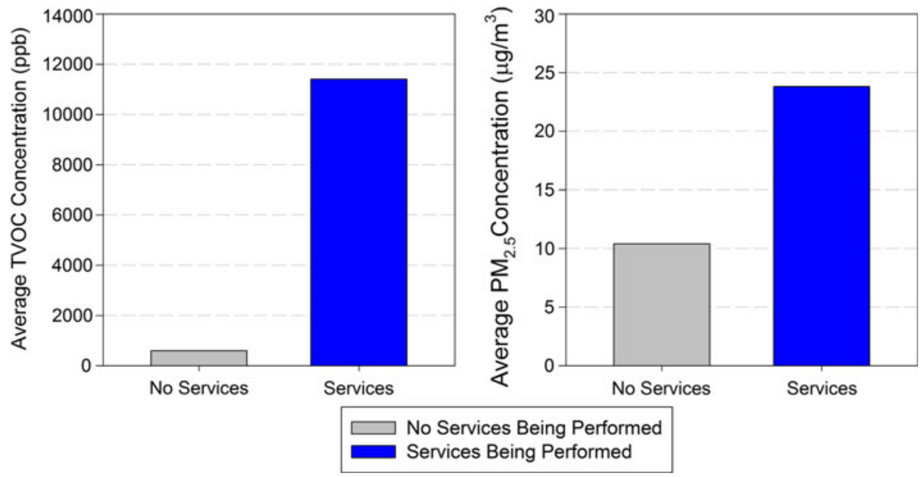

Fig. 3 Salon average TVOC and $PM_{2.5}$ concentrations stratified by whether or not services were being performed at the time of sampling

Our study has several limitations. Our samples were collected using a convenience recruitment design that may not be representative of all nail salons. The recruitment list included salons that had already been in contact with the Boston Public Health Commission and therefore may represent salons with a higher likelihood of compliance with regard to standard practices, including worker protections. Additionally, the sampling plan was limited to the collection of TVOCs as opposed to individual compounds; there are no health standards for TVOC exposure. We focused on airborne exposures as they relate to ventilation characteristics and thus did not attempt to determine chemical exposure through other exposure pathways, including incidental dust ingestion and dermal adsorption. Thus, total exposures to specific compounds cannot be determined. Last, the concentrations reported in our study represent short-term measurements and may not be representative of annual average exposures or conditions.

To reduce chemical exposures in nail salons, owners should evaluate three strategies: source removal or substitution, engineering controls, and personal protective equipment (PPE). The most effective approach is to substitute current product lines with low-VOC or non-toxic alternatives. If source removal is not feasible, engineering controls designed to improve general ventilation and/or provide local ventilation will reduce exposures of both TVOCs and $PM_{2.5}$. The results of our study indicate that the ventilation in most salons is currently inadequate. Our results show that simple procedures, such as opening doors and windows when the weather permits, can reduce exposures. Implementing controls through personal protective equipment may be the most challenging option. During our study, we learned that some nail salon workers use surgical masks as personal protective equipment, but these masks do not protect from chemical vapors and dust. Our observations are consistent with a study of nail salon workers that found that 90 percent of nail technicians wear infection control masks and believe that it will protect them from dust and chemical fumes [19]. The Boston Safe Shops project attempts to educate workers and employers on the proper use of NIOSH approved N95 respirator to mitigate dust exposure; however our survey indicated that use of surgical masks is still widespread. Also, while the N95 respirators are capable of reducing exposures to particulate matter, these respirators do not provide protection to gaseous chemicals.

The results of this study demonstrate that the nail salon workforce is exposed to TVOCs that exceed typical levels found in residential and possibly other occupational environments. We also found that improving ventilation conditions in salons to meet minimum outdoor air delivery requirements can reduce exposures to TVOCs. Additional studies are warranted and should focus on characterizing full-shift occupational exposures by monitoring breathing zone concentrations for individual VOCs.

Acknowledgments We thank the salon workers and salon owners for participating in our study, and our collaborators at Viet-AID and BPHC.

Conflict of interest None.

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